DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

MISSISSIPPI RIVER COMMISSION

LABORATORY INVESTIGATION OF FILTERS FOR
ENID AND GRENADA DAMS

TECHNICAL MEMORANDUM NO. 3-245

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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CONTENTS

LABORATORY INVESTIGATION OF FILTERS FOR

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SYNOPSIS

Before final selection of the filters for Enid and Grenada Dams was made, laboratory tests were performed to check the stability of all filters which had been proposed for use. Tests were also made of a locally available sandy gravel to determine if it could be satisfactorily used for the gravel blanket beneath the dumped riprap on the upstream slopes.

On the basis of the laboratory tests, three filters, C, D, and S were selected for use in the design of the drainage facilities for these dams. Gravel D would be used for draining silty sands and all finer-grained soils; gravel S, as a filter to drain sands and as a filter for the relief wells along the toe of the dams; and gravel C, as a filter to drain gravels D or S and as a water-carrying layer of gravel.

Tests on the locally available sandy gravel indicated that a satisfactory gravel blanket beneath the riprap at these dams could be developed by using all the sand and gravel coarser than a No. 28 Tyler sieve, placing this as a 12- or 15-in. layer, and harrowing until the bottom 3 in. consists of particles 25 per cent of which are finer than 2 mm and the top 3 in. consists of gravel 30 per cent of which is larger than 1 in.

The tests also indicated that the filter criterion, $\dfrac{D_{15} \text{ Filter}}{D_{85} \text{ Base}} < 5,$

is satisfactory for designing filters where the filter and base materials are more or less uniformly graded without any particular excess or lack of certain particle sizes. However, the tests did indicate the desirability of the following additional criteria for stability:

$$\frac{D_{15} \text{ Filter}}{D_{15} \text{ Base}} < 20 \qquad \text{and} \qquad \frac{D_{50} \text{ Filter}}{D_{50} \text{ Base}} < 25.$$

PART I: INTRODUCTION

General

1. The investigation of filters for Enid and Grenada Dams was authorized by the President, Mississippi River Commission, in a letter dated 16 September 1946, subject, "Review of Final Drawings for Grenada Dam". Authority to conduct additional studies was contained in subsequent correspondence.

2. The tests were conducted in the Embankment and Foundation Branch of the Soils Division, Waterways Experiment Station. Engineers actively connected with the investigation were Messrs. W. J. Turnbull, S. J. Johnson, C. I. Mansur, and G. E. Olson. Testing was performed under the direction of Mr. Olson; this report was prepared by Mr. Mansur and Mr. Olson.

3. The principal objectives of the investigation were to:

   a. Check the designs of various proposed filters for Enid and Grenada Dams.

   b. Review the design of the gravel blankets beneath the dumped riprap on the upstream slopes of Enid and Grenada Dams with a view toward utilizing, with a minimum of processing, a sandy gravel locally available.

   c. Observe the validity of the filter stability criterion

$$\frac{^{*}D_{15} \text{ Filter}}{D_{85} \text{ Base}} < 5.$$

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* D — the grain size on a mechanical analysis curve corresponding to the percentage of particles by weight having diameters smaller than D for the percentage indicated by subscript (e.g. D_{15}).

Scope

4. Laboratory filter tests were made of all filters and combinations thereof proposed for Enid and Grenada Dams. A summary of these tests is given by the following tabulation. The gradations of the various materials tested are shown subsequently in this report.

Group I — Tests on Proposed Filter Materials

Test	Perforations Adjacent to Filter	Filter Gravel	Base	Remarks
1	1/2 in.	A	B	Gravel A, a filter adjacent to drainage collector pipes with 1/2-in. perforations, to serve as a water-carrying drainage blanket, and to drain filter gravel B. Gravel B, a filter to drain sand or pervious backfill.
2	1/4- x 2-in. slots	A	B	
3	1/2 in.	A_{max}	B_{min}	
4	1/2 in.	A	D	Gravel D, a filter to drain fine-grained or impervious soils.
5	1/2 in.	A_{max}	D_{min}	
6	-----	B	Soil V	A test to check limit of filter criteria. Soil V, a sandy silt.
7	-----	B	Sand U	Sand U, a fine to medium sand.
8	-----	B_{max}	Sand X	Sand X, a very uniform fine sand.
9	1/2 in.	C	D	
10*	-----	C_{max}	D_{min}	Gravel C, a filter to drain gravel D and to serve as a water-carrying layer.
11*	-----	C	D	
12	-----	D	Soil V	Gravel D, a filter to drain fine-grained soils. Soil V, a sandy silt.

Group I -- Tests on Proposed Filter Materials (Con'd)

Test	Perforations Adjacent to Filter	Filter Gravel	Base	Remarks
13	1/2 in.	F	D	Gravel F, a filter to go beneath dumped riprap and to drain gravel D.
14	1/2 in.	F_{max}	D_{min}	
15	1/2 in.	F_{max}	Sand L_{min}	Sand L, a local Grenada material suggested by MRC for consideration as a substitute for gravel D.
16	3/8-in. holes	W	Sand Y	Gravel W, a filter for relief wells. Sand Y, a fine to medium sand.
17	1/4- x 2-in. slots	W	Sand Y	
18	1/2-in. holes	W	----	A test to check the limiting size of perforations suitable for draining gravel W.

* Upward flow.

5. In addition to the tests shown in paragraph 4, a rather extensive series of tests was performed in an effort to design a satisfactory filter blanket, or blankets, beneath the dumped riprap on the upstream slope of Grenada Dam, utilizing materials from a local sand-gravel pit (Harrison) at Scobey, Miss. These tests are outlined in the tabulation on the following page. The filters and most of the bases shown are average Harrison pit-run material screened as indicated. The tests are based on samples from the Harrison pit furnished the Experiment Station by the Vicksburg District Office and were assumed to be representative of this pit. Because of the similarity of the gravel in the gravel borrow areas for Enid Dam to the gravel from the Harrison pit, it was considered that the results of the following tests for Grenada Dam would also be applicable to Enid Dam.

Group II — Tests on Harrison Pit Sand-Gravel Materials

Test	Filter*	Base*	Remarks
19	H > #4	H < #4	Downward flow.
20	H > #4	H < #4	Upward flow.
21	H	None	Upward flow. Material thoroughly harrowed, 12-in. layer.
22	H > #10	H	Downward flow.
23	H > #10	H	Upward flow.
24	H > #10	H < 3/4 in.	Upward flow.
25	H > #10	H < 1/2 in.	Upward flow.
26	H > #10	H < 1/2 in.	Upward flow. Filter harrowed.
27	H > #10	H < #10	Downward flow.
28	H > #10	Sand R	Upward flow. Filter harrowed. Sand R very fine.
29	H > #28	None	Upward flow. Filter harrowed.
30	H > #28	Sand R	Upward flow. Filter harrowed. Sand R very fine.

* The Harrison pit or H-filters and bases of group II are designated as being "greater than" or "less than" certain Tyler screens. In all cases the material finer than a 65-mesh screen was discarded.

6. As these experiments were exclusively concerned with the stability of various filters and base combinations, permeability measurements were made in only a few instances.

Review of Filter Design Criteria

7. A properly designed filter must possess the following two properties: (a) it must be many times more pervious than the base to effectively drain it; and (b) it must be of such gradation that the base material will not migrate through its voids. Terzaghi has suggested that a filter will have these properties if it meets the following criteria:

Stability $\quad\dfrac{D_{15}\ \text{Filter}}{D_{85}\ \text{Base}} < 4^{*}\qquad$ herein called "stability ratio"

Permeability $\quad\dfrac{D_{15}\ \text{Filter}}{D_{15}\ \text{Base}} > 4\qquad$ herein called "permeability ratio"

Where a filter is to be drained by a perforated collector pipe, the Experiment Station uses the following criteria for determining the size of perforations:

For circular holes $\qquad\dfrac{D_{85}\ \text{Filter}}{\text{Hole diam.}} > 1.0$

For slots $\qquad\dfrac{D_{85}\ \text{Filter}}{\text{Slot width}} > 1.2$

A filter which satisfies the above criteria may yet fail if it has an excess or lack of certain sizes or is not uniformly graded. Therefore, the Experiment Station uses in addition to the above criteria the further stipulations:

> a. The gradation curve of the filter should be more or less parallel to the gradation curve of the base or material being drained for adequate stability. In general, as a tentative requirement, the ratio D_{15} of filter to D_{15} of base should be less than 20 and the ratio D_{50} of filter to D_{50} of base should be less than 25.
>
> b. The filter should be well graded from its maximum to its minimum size, with no large excess or lack of intermediate sizes. A lack of intermediate sizes increases the tendency toward segregation.

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* Previous tests by the Experiment Station, described in Technical Memoranda 183-1 "Investigation of Filter Requirements for Underdrains" and 195-1 "Field and Laboratory Investigation of Design Criteria for Drainage Wells", indicate that a stability ratio of 5.0 may be used, if necessary, for setting the maximum gradation of a filter band where both the filter and the base are more or less uniformly graded.

8. The criteria set forth in the above paragraph were used for designing all the filters for Enid and Grenada Dams except the filters draining very fine-grained soils (clay silts and finer). The same filter was used to drain these latter soils as was used for sandy silts on the basis that any filter which will satisfactorily drain a uniform sandy silt will also satisfactorily drain any finer-grained soil because the seepage velocities through the latter soils are so low that they will not move particles of soil.

9. The requirements for filters beneath riprap on the slopes of a dam are not very well known. However, such filters must be stable within themselves in order not to erode as a result of wave action. A filter material adjacent to a sand embankment should meet the criteria for filters enumerated in paragraph 7, as drawdown and wave action will cause flow of water out of the embankment into the filter; and the filter material adjacent to the riprap must have a size and gradation which will not be sucked or washed out through the riprap as a result of wave action. There are no known suitable laboratory tests to check the design of filters in contact with riprap. A study of the performance of riprap and gravel blankets on the upstream slopes of various dams in the United States is now being made by the Office, Chief of Engineers.

Considerations on Laboratory Filter Tests

10. In most filter tests performed in the past by this and other agencies, the combination of base and filter was subjected to downward flow and was sometimes tapped to induce vibration. If the filter and base materials are held rigidly in place with an adequate surcharge,

there probably is little difference between the effects of upward flow
or downward flow on the stability of a filter, unless the gradients are
high or the filter combination is subjected to vibration.

11. Whether or not the filter and base materials should be vibrated
and how much vibration should be applied during testing are not known. In
most instances, filters in the field are not subjected to vibration. Ex-
ceptions might be filters in the vicinity of spillways or outlet works,
where the flowing water may create a certain amount of vibration in the
ground; filters beneath riprap, where they might be subjected to vibra-
tion induced by wave action; filters located beneath or adjacent to
roadways and runways; and possibly filters for structures located in
a region subject to many earthquakes. Tapping may impose an excessively
severe condition on a filter, unless it is known that the filter will be
subjected to similar vibration in the prototype. A certain amount of
tapping is usually included in most laboratory tests to compensate for
the fact that laboratory tests are usually of short duration compared
with field operation.

12. No conclusive evidence is available to indicate to what extent
surging of filters should be included in the testing procedure. It is
believed that surging, at least to some extent, should be included, since
this may compensate for the fact that laboratory filter tests are gen-
erally of short duration. In order to simulate the many variations of
flow likely to occur in the field over a long period of time, the surging
should be repeated a considerable number of times. Surging, as used in this
investigation, consisted of rapidly changing the hydraulic gradient
through the base material.

13. It is rather doubtful that a suitable type of test can be devised in the laboratory to check adequately the stability of a filter blanket beneath riprap exposed to wave action. Two possible methods of investigation for arriving at proper stability characteristics of the filters are:

    a. A study and analysis of the performance of riprap and filters on existing dams.

    b. Experiments in a large wave tank in which full-scale riprap and waves can be duplicated.

A material directly beneath riprap should be stable within itself against the flow of water through it, and this condition can be duplicated in the laboratory. No material which cannot pass this test should be used beneath riprap. In a further effort to duplicate field conditions, the filter combinations to be used in conjunction with riprap should be subjected to a surging action.

14. One factor not taken into account in this series of tests was the effect of time. It was believed that time would not appreciably affect the results of tests made with clean sands or gravels, except where the water was of such nature that it would permit the growth of iron bacteria or algae or would permit the deposition of mineral deposits on the sand or gravel particles. Such possibilities are not common occurrences and are not considered in the design of a filter. Where very fine-grained soils are being drained, time may have a more important effect. At the present, however, there are no known laboratory data on this feature and it was not considered in this investigation.

PART II: LABORATORY TESTS

General

15. In multilayered filters, a gravel may act as a filter and at the same time it may serve as a base for another coarser filter. As an example, in test 1 gravel A is the filter material and gravel B is the base material. In test 6 gravel B is used as a filter to drain a foundation material, soil V. Thus it is seen that gravel B is used in one case as a base and in the other as a filter for test purposes. In order to systematize the presentation of test data, all test combinations which have a common filter are grouped together under the filter (see table 1) and are discussed in that order.

16. A summary of the tests, including various filter ratios, method of testing, and results, is given in table 1. It is to be noted that for some tests the flow was downward and in others it was upward. Also, some combinations were subjected to surging while others were not.

Apparatus

17. The filter tests outlined in the previous paragraphs were made in an 8-in. transparent pyralin permeameter shown schematically in figure 1. In all tests where flow was downward the filter material was supported by either a perforated disc or a wire screen; the base or foundation material was placed on top of the filter. A baffle plate immediately below the inlet prevented concentration of flow at any one point. A plate on top of the permeameter permitted tests at high
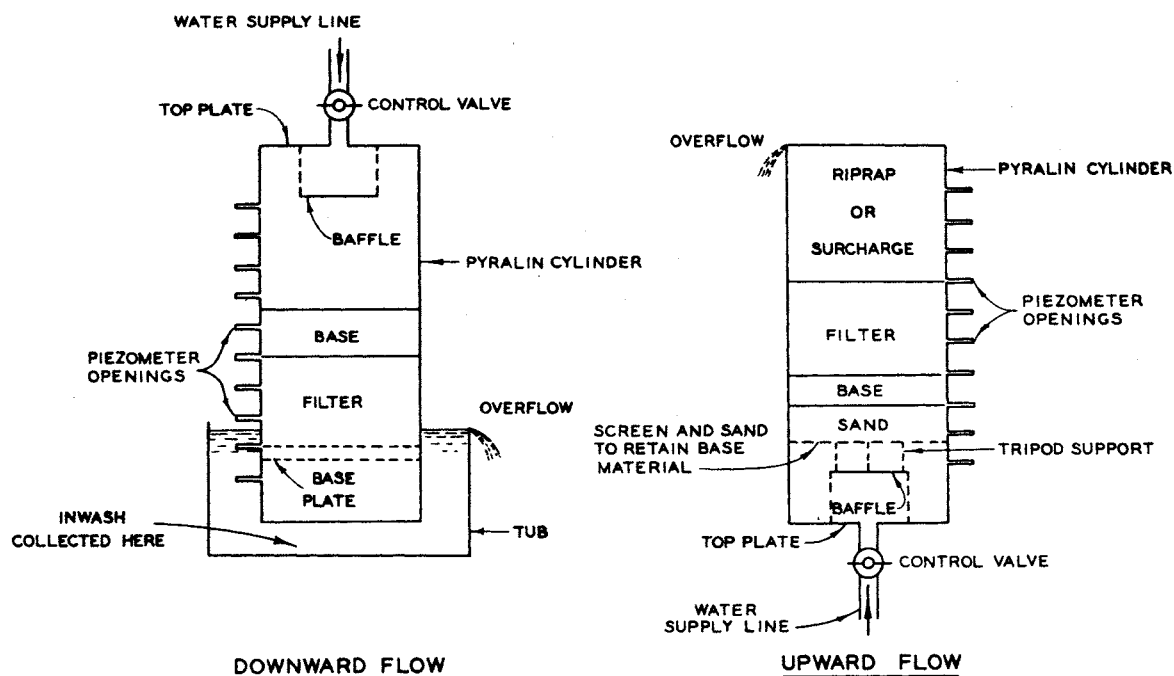
Figure 1. Filter testing apparatus
for downward and upward flow tests

hydraulic gradients through the base and filter layers. Flow and pressure gradients were controlled by a gate valve in the supply line. The flow was measured as it was discharged from the stilling basin (a tub). Any inwash of material was collected in the tub for weighing and analysis. Head losses through the base and filter materials were measured by piezometers located at various points in the cylinder.

18. For the upward flow tests, the apparatus was inverted so that a hydrostatic pressure could be maintained at the bottom of the permeameter (see fig. 1). The base material was placed on the bottom and supported by a fine screen; for very fine base materials a thin layer of sand was placed over the screen before the base was placed.

Materials Tested

19. The filters tested were divided into two main groups: group
I (tests 1-18), the tentative filter designs outlined in paragraph 4; and
group II (tests 19-30), the Harrison pit material tested to develop a
suitable blanket beneath dumped riprap as outlined in paragraph 5. The
materials for the first series of tests were prepared in the laboratory
by blending previously-screened sands and gravels so as to obtain the
exact filter or base material desired. Except for the very fine base
materials, the various filters and bases for tests 19-30 were obtained
by screening a composite sample of material from the Harrison sand-gravel
pit.

20. The filters in group I were prepared to duplicate the tenta-
tive filter designs for Enid and Grenada Dams. The filters are designated
by the same letters which identify them on plans and in specifications
for these projects. A subscript of "max" indicates that material was of
the maximum gradation which would fall within the allowable band of that
filter. Similarly, the subscript "min" applies to the minimum gradation.
A letter with no subscript indicates that the material tested represented
as nearly as possible its average gradation.

Testing Procedures

21. The filter and base materials were placed in the apparatus dry
and in lifts to avoid segregation. In those tests using downward flow,
a 6-in. layer of filter gravel was placed in the bottom of the permea-
meter above a wire screen with a mesh size larger than the maximum size

of the base material. This screen held the filter material in place but did not retain any base material which migrated through the filter. The top of the filter was smoothed off before a 3-in. layer of base material was placed. The levels of both materials were carefully marked on the outside of the permeameter.

22. The base and filter were first subjected to a hydraulic gradient of 1.0 through the base material, and observations were made for any movement of the base into or through the filter. If there was no indication of movement, the gradient was increased in steps to the maximum attainable with the available water source, or until failure occurred. The maximum hydraulic gradient approached 25 in several tests, although this value was difficult to achieve for the coarse, very permeable base materials. If the test materials were stable under these conditions, the tests were repeated at the same gradients and the permeameter vibrated by tapping it with a small hammer approximately 100 times per minute for ten minutes at each gradient. If the filter-base combination was stable with tapping, it was then subjected to surging by changing the gradient from 0 to 10 several times as rapidly as the inflow valve could be manipulated. Careful observation for grain movement, piping, settlement, or other indications of failure was maintained. All tests were continued to either complete failure, partial failure (excessive infiltration of material into or through the filter but eventual stabilization), or stability, as indicated by little or no passage of the base material into or through the filter.

23. In the tests with upward flow, the base material was placed on a very fine screen and/or layer of sand in the bottom of the cylinder.

A 6-in. layer of filter material was placed next, followed by a surcharge of coarse stones and lead weights. With the test materials in place, water was forced upward under low head to eliminate any entrapped air without displacing the grains. In these tests, a hydrostatic pressure was maintained in the bottom of the permeameter so as to force water upward through the base and filter materials. The filter-base combinations were subjected to a series of flows at increasing gradients until failure occurred or until observations indicated the base and filter were stable. If both materials were stable for steady flow, the combination was subjected to surging. If the materials under test were stable with repeated surging, the test was then continued and the permeameter tapped while a high hydraulic gradient was maintained. The test was continued until failure of the filter-base combination occurred or until stabilization was indicated by no further movement of materials.

24. Tests using only one layer of material were made to determine whether the material was stable within itself or whether the lack or excess of certain particular sizes would cause it to segregate when subjected to the flow of water. The instability of a given material was demonstrated when a large component of the material washed out of the sample under low gradients.

TABLE 1

Summary of Test Results

| | | | Ratio of Sizes -- Filter to Base | | | | | | | |
| | | | Stability Ratio | Perm. Ratio | | | | | Flow Direction | |
Test No.	Material Filter	Base	$\dfrac{D_{15}\ (F)}{D_{85}\ (B)}$	$\dfrac{D_{15}\ (F)}{D_{15}\ (B)}$	$\dfrac{D_{50}\ (F)}{D_{50}\ (B)}$	Steady Flow	Vibra-tion	Surg-ing	Down	Up
1	A	B	1.0	6.3	5	Stable	Stable	–	x	–
2	A	B	1.0	6.3	5	Stable	Stable	–	x	–
3	A max	B min	1.8	10.0	8	Stable	Stable	–	x	–
4	A	D	1.3	15.5	6	Stable	Stable	–	x	–
5	A max	D min	2.3	23.0	16	Stable	Failed	–	x	–
6	B	Soil V	11.0	28.0	47	Failed	–	–	x	–
7	B	Sand U	1.6	5.0	7	Stable	Stable	–	x	–
8	B max	Sand X	5.2	8.8	15	Stable	Failed	–	x	–
9	C	D	0.8	10.0	9	Stable	Stable	–	x	–
10	C max	D min	1.4	20.0	18	Stable	Partial Failure	Stable	–	x
11	C	D	0.9	11.0	9	Stable	Stable	Stable	–	x
12	D	Soil V	4.8	12.0	28	Stable	Stable	–	x	–
13	F	D	1.2	14.0	12	Stable	Stable	–	x	–
14	F max	D min	2.1	24.6	27	Stable	Failed	–	x	–
15	F max	L min	3.9	29.0	45	Stable	Failed	–	x	–
16	W	Sand Y	2.7	8.2	14	Stable	Stable	–	x	–
17	W	Sand Y	2.7	8.2	14	Stable	Stable	–	x	–
18	W	None	----	----	--	Stable	Stable	–	x	–
19	H > #4	H < #4	4.7	24.0	42	Stable	Failed	–	x	–
20	H > #4	H < #4	4.7	24.0	42	Failed	–	–	–	x
21	*H	None	----	----	--	Failed	–	–	–	x
22	H > #10	H	0.18	9.8	3	Stable	Failed	–	x	–
23	H > #10	H	0.18	9.8	3	Stable	–	Failed	–	x
24	H > #10	H < 3/4 in.	0.45	11.0	15	Stable	Failed	–	–	x
25	H > #10	H < 1/2 in.	0.74	12.0	18	Stable	Failed	Failed	–	x
26	*H > #10	H < 1/2 in.	0.74	12.0	18	Stable	–	Failed	–	x
27	H > #10	H < #10	7.3	17.0	36	Failed	–	–	x	–
28	*H > #10	Sand R	31.0	84.0	180	Failed	–	–	–	x
29	*H > #28	None	----	----	--	Stable	Stable	Stable	–	x
30	*H > #28.	Sand R	----	----	--	Stable	Stable	Stable	–	x

* Harrowed

PART III: RESULTS OF TESTS*

Group I -- Proposed Filters

Filter A

25. Filter A** (tests 1-5, figure 2) was originally designed for use adjacent to collector pipes with 1/2-in. perforations, and to serve as a water-carrying layer and as a filter layer for gravel B, which was proposed as a filter for draining sand or pervious backfill. Gravel A was a rather uniform coarse to medium gravel, ranging from 1 in. to approximately 1/4 in. In addition to the three tests with gravel B as a base material, two tests were run with gravel D as a base to see if a filter would be stable which met the usual filter stability criteria but was not well graded or parallel to the gradation of the base material. Test results are presented in the following paragraphs.

26. Test 1 (filter A vs base B). Wooden base plate with 1/2-in. holes.

$$\frac{D_{85}\ (A)}{1/2\text{-in. holes}} = 1.4 \qquad \frac{D_{15}\ (A)}{D_{15}\ (B)} = 6.3$$

$$\frac{D_{15}\ (A)}{D_{85}\ (B)} = 1.0 \qquad \frac{D_{50}\ (A)}{D_{50}\ (B)} = 5.0$$

Filter A was stable with respect to the 1/2-in. holes and to base B for steady flow and with vibration.

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* A summary of all test results is given in table 1.

** Letter always refers to same material, whether designated as filter or gravel.
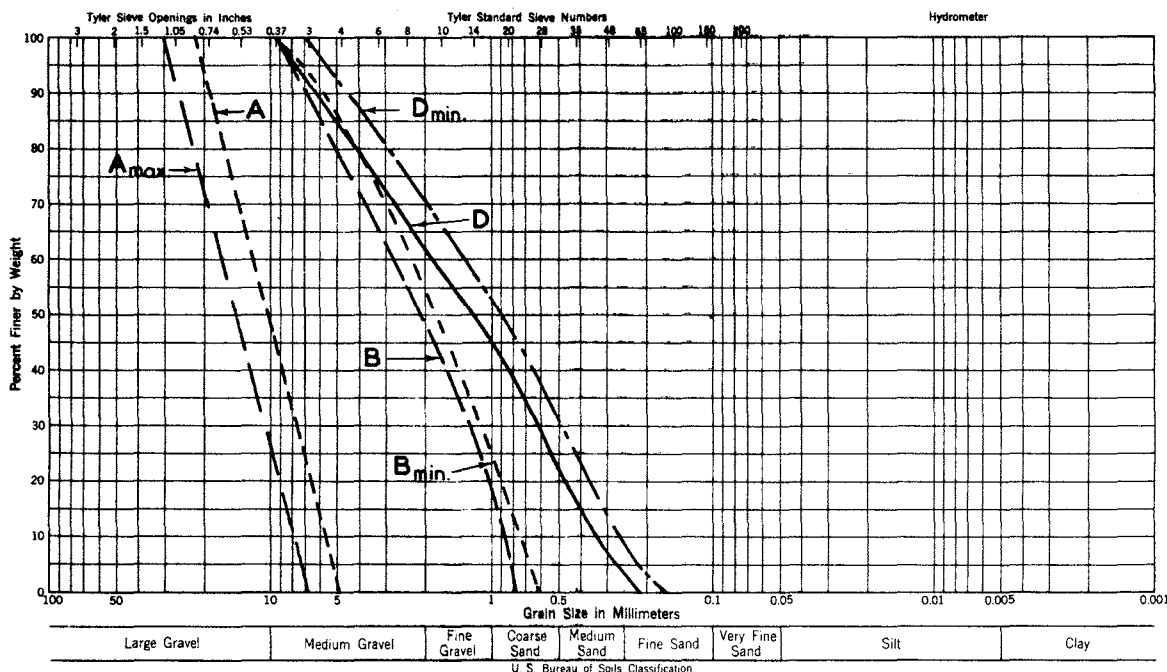
Figure 2. Tests 1 to 5 -- gravels A, B, and D

27. <u>Test 2 (filter A vs base B)</u>. Wooden base plate with 1/4-in.
by 2-in. slots. Test was the same as test 1 except for slots in base
plate, $\dfrac{D_{85}\ (A)}{1/4\text{-in. slots}} = 2.9$. The combination was stable for steady flow
and with vibration.

28. <u>Test 3 (filter A_{max} vs base B_{min})</u>.   Base plate 1/2-in. wire
screen.

$$\frac{D_{85}\ (A)_{max}}{1/2\text{-in. screen}} = 2.0 \qquad\qquad \frac{D_{15}\ (A)_{max}}{D_{15}\ (B)_{min}} = 10$$

$$\frac{D_{15}\ (A)_{max}}{D_{85}\ (B)_{min}} = 1.8 \qquad\qquad \frac{D_{50}\ (A)_{max}}{D_{50}\ (B)_{min}} = 8$$

This combination was stable with steady flow and with vibration.

29. <u>Test 4 (filter A vs base D)</u>. Base plate 1/2-in. wire screen.

$$\frac{D_{85}\ (A)}{1/2\text{-in. screen}} = 1.5 \qquad\qquad \frac{D_{15}\ (A)}{D_{15}\ (D)} = 16$$

$$\frac{D_{15} (A)}{D_{85} (D)} = 1.3 \qquad\qquad \frac{D_{50} (A)}{D_{50} (D)} = 8$$

This combination was stable with steady flow and with vibration.

30. <u>Test 5 (filter A_{max} vs base D_{min})</u>. Base plate 1/2-in. wire screen.

$$\frac{D_{85} (A)_{max}}{1/2\text{-in. screen}} = 2.0 \qquad\qquad \frac{D_{15} (A)_{max}}{D_{15} (D)_{min}} = 27$$

$$\frac{D_{15} (A)_{max}}{D_{85} (D)_{min}} = 2.2 \qquad\qquad \frac{D_{50} (A)_{max}}{D_{50} (D)_{min}} = 16$$

This combination was stable for steady flow with a hydraulic gradient of about 20 through the layer of base material. However, continued tapping with a steel hammer for about 80 minutes caused the fines in D_{min} less than the No. 10 seive size to wash out of the base and through filter A_{max}. There was also some migration of coarser particles of D_{min} into filter A_{max}. The stability ratio indicates that this combination of filter and base should be stable, which it was for steady flow. The probable causes of failure with vibration were the lack of any small gravel in filter A_{max} and the excessively high ratio of the 15 per cent sizes.

<u>Filter B</u>

31. Gravel B (tests 6-8, figure 3) was a fairly uniform, medium to fine gravel which was proposed as a filter adjacent to sand. It was to have been drained by filter A, as discussed in paragraph 25. The suitability of gravel A for draining gravel B was verified in tests 1, 2 and 3. The purpose of tests 6, 7, and 8 was to determine whether or not filter B would successfully drain sand. Three materials, a sandy silt
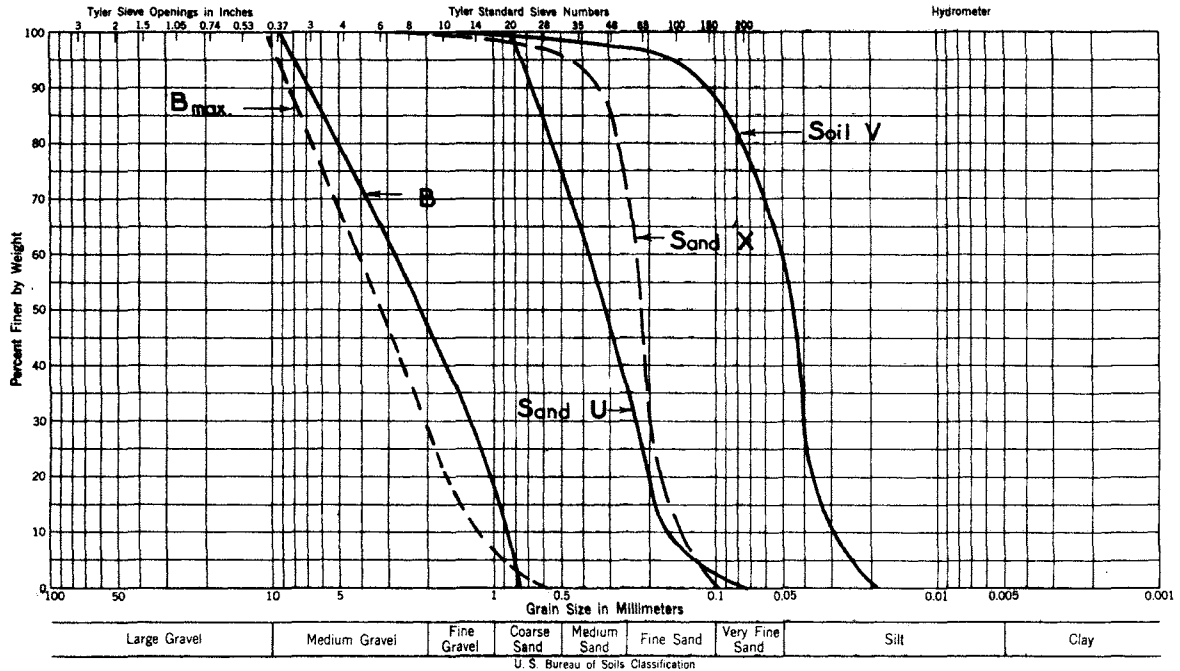
Figure 3. Tests 6, 7, and 8 — gravel B, sands U and X, and soil V

(soil V), a fine to coarse sand (U), and a very uniform fine sand (X), were used as foundation materials in these tests. The results of these tests are described below.

32. Test 6 (filter B vs soil V). Base plate, 14-mesh screen.

$$\frac{D_{85}\ (B)}{\#14\ \text{screen}} = 6 \qquad\qquad \frac{D_{15}\ (B)}{D_{15}\ (V)} = 28$$

$$\frac{D_{15}\ (B)}{D_{85}\ (V)} = 11 \qquad\qquad \frac{D_{50}\ (B)}{D_{50}\ (V)} = 47$$

As might be expected from the above filter ratios, this combination of filter and base materials proved unstable (piping occurred) with steady flow and a hydraulic gradient of only 2 through the base material. The instability of this combination was further proved by continued piping,

even with the addition of more base material. Therefore it may be con-
cluded that gravel B would be too coarse to serve as a filter for silty
sands or sandy silts.

33. <u>Test 7 (filter B vs Sand U)</u>. Base plate, 14-mesh screen.

$$\frac{D_{85} \ (B)}{\#14 \ screen} = 5.1 \qquad\qquad \frac{D_{15} \ (B)}{D_{15} \ (U)} = 5.0$$

$$\frac{D_{15} \ (B)}{D_{85} \ (U)} = 1.6 \qquad\qquad \frac{D_{50} \ (B)}{D_{50} \ (U)} = 7.0$$

This combination was stable with steady flow and with vibration. It
might be stated that gravel B would be an ideal filter for a sand such
as U. However, because of the fact that filter B might be required to
drain a sand finer than sand U, another test was run (test 8) using the
maximum gradation of B and a very uniform, fine sand X.

34. <u>Test 8 (filter B_{max} vs sand X)</u>. Base plate, 8-mesh screen.

$$\frac{D_{85} \ (B)_{max}}{\#8 \ screen} = 3.1 \qquad\qquad \frac{D_{15} \ (B)_{max}}{D_{15} \ (X)} = 8.8$$

$$\frac{D_{15} \ (B)_{max}}{D_{85} \ (X)} = 5.2 \qquad\qquad \frac{D_{50} \ (B)_{max}}{D_{50} \ (X)} = 15.0$$

Filter B_{max} and sand X were stable for a condition of steady flow, but
when the combination was subjected to tapping at a hydraulic gradient of
about 1, failure took place by slow migration of sand X into and through
filter B_{max}. One small pipe hole developed in sand X during the test.
Even though gravel B_{max} proved satisfactory for draining a fine sand such
as X without vibration, the test demonstrates rather definitely that the
ratio $\frac{D_{15} \ Filter}{D_{85} \ Base}$ should not exceed 5.0. The stability ratio for this

test was 5.2. Filter B should not be used as a filter where base material
of uniform "fine" or "very fine" sands might be encountered.

Filter C

35. Filter C (tests 9-11, figure 4) was designed to drain gravel
D (discussed in paragraph 39) and to serve as a water-carrying layer of
gravel, the water in which would be collected by perforated pipes with
1/2-in. holes. Gravel C was a large to medium gravel, grading from a
2-in. maximum size to a No. 8 Tyler screen. It was tested in combination
with gravel D with downward flow (test 9) and upward flow (tests 10 and
11). Gravel D had a gradation ranging from medium sand to medium gravel.
The results of these tests are presented below.

36. **Test 9 (filter C vs base D)**. Base plate, 1/2-in. wire screen.

$$\frac{D_{85}\,(C)}{1/2\text{-in. screen}} = 2.2 \qquad\qquad \frac{D_{15}\,(C)}{D_{15}\,(D)} = 10.0$$

$$\frac{D_{15}\,(C)}{D_{85}\,(D)} = 0.8 \qquad\qquad \frac{D_{50}\,(C)}{D_{50}\,(D)} = 9.0$$

As might be expected from the above filter ratios, this combination was
stable for steady flow, vibration, and surging.

37. **Test 10 (filter C_{max} vs base D_{min})**.

$$\frac{D_{15}\,(C)_{max}}{D_{85}\,(D)_{min}} = 1.4 \qquad \frac{D_{15}\,(C)_{max}}{D_{15}\,(D)_{min}} = 20 \qquad \frac{D_{50}\,(C)_{max}}{D_{50}\,(D)_{min}} = 18.0$$

In this test the flow was upward. The combination was stable for steady
flow, for violent surging, and for normal tapping. However, when the
combination was subjected to severe tapping, some fines were observed

migrating from the base through the filter to form sand boils on top of
the filter. When tapping was stopped, the passage of fines ceased.
This combination of filter and base should theoretically be stable. As
this combination represents the worst possible combination of gravels
C and D, and as it was stable for all test conditions except that created
by severe tapping, gravel C_{max} may be considered satisfactory.

38. Test 11 (filter C vs base D). The filter and base materials
in this test were the same as in test 9. The test differed only in that
the flow was upward rather than downward. The combination was stable
under all test conditions of steady flow, severe surging, and tapping.
This test, together with test 9, definitely indicates the stability of
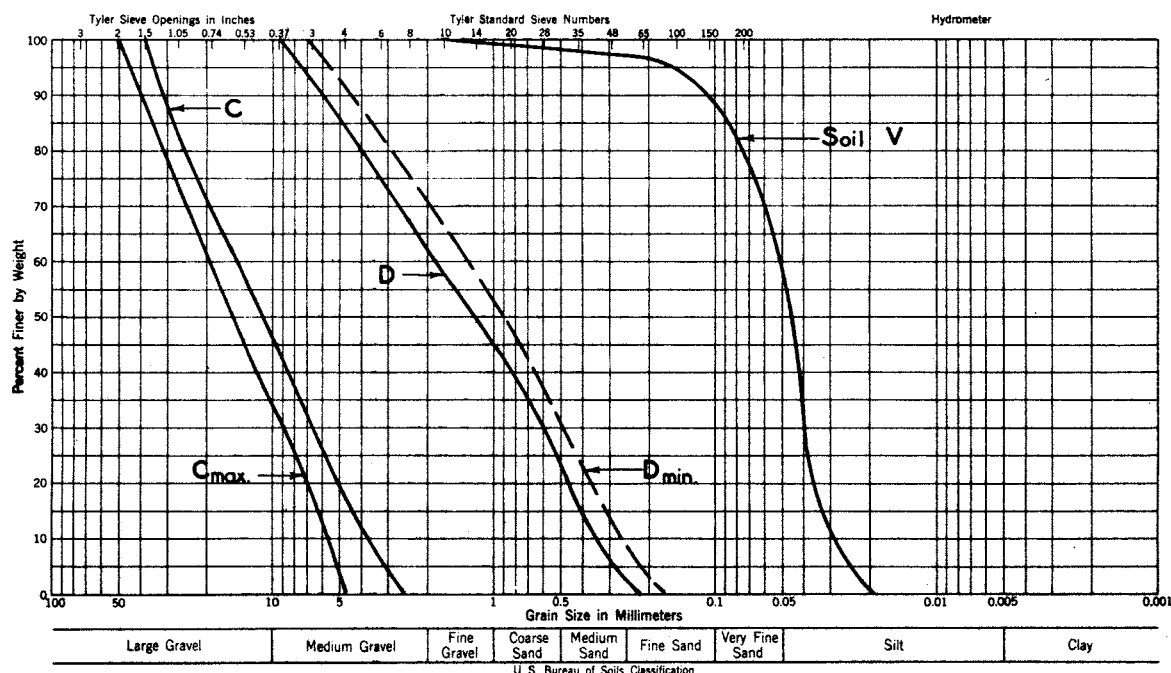the average gradation of filter C when tested with the average gradation
of base D.

Figure 4. Tests 9 to 12 — gravels C and D, and soil V

Filter D

39. Filter D (test 12, figure 4) was designed to drain fine-grained

soils in combination with filter gravels A and C. Soil V, a very uniform

sandy silt (uniformity coefficient = 1.7), was chosen as the base material

in this test. It is believed that any filter which will satisfactorily

drain this material will drain any finer soil. Soil V was a cohesionless

and very fine material extremely susceptible to piping.

$$\frac{D_{15}\ (D)}{D_{85}\ (V)} = 4.8 \qquad \frac{D_{15}\ (D)}{D_{15}\ (V)} = 12.0 \qquad \frac{D_{50}\ (D)}{D_{50}\ (V)} = 28$$

In this test the combination proved stable with steady downward flow at

various gradients and also when vibrated severely while subjected to a

hydraulic gradient over 100. It is believed that gravel D is a satis-

factory filter for relatively impervious materials such as sandy silts

and all finer soils, since the flow in finer soils would probably be so

low that there would be little or no movement of the grains.

Filter F

40. Filter F (tests 13-15, figure 5), a coarse, well-graded gravel

(3 in. to No. 6 Tyler sieve), was originally designed to be placed under

dumped riprap as part of the upstream slope protection and to drain an

intermediate layer of gravel D placed adjacent to the embankment. Con-

sequently, the filter has to be coarse enough to insure stability with

respect to the dumped riprap, yet fine enough to successfully hold back

gravel D. In checking filter F, three tests were run: one using the

average gradation of gravels F and D; one using the maximum permissible

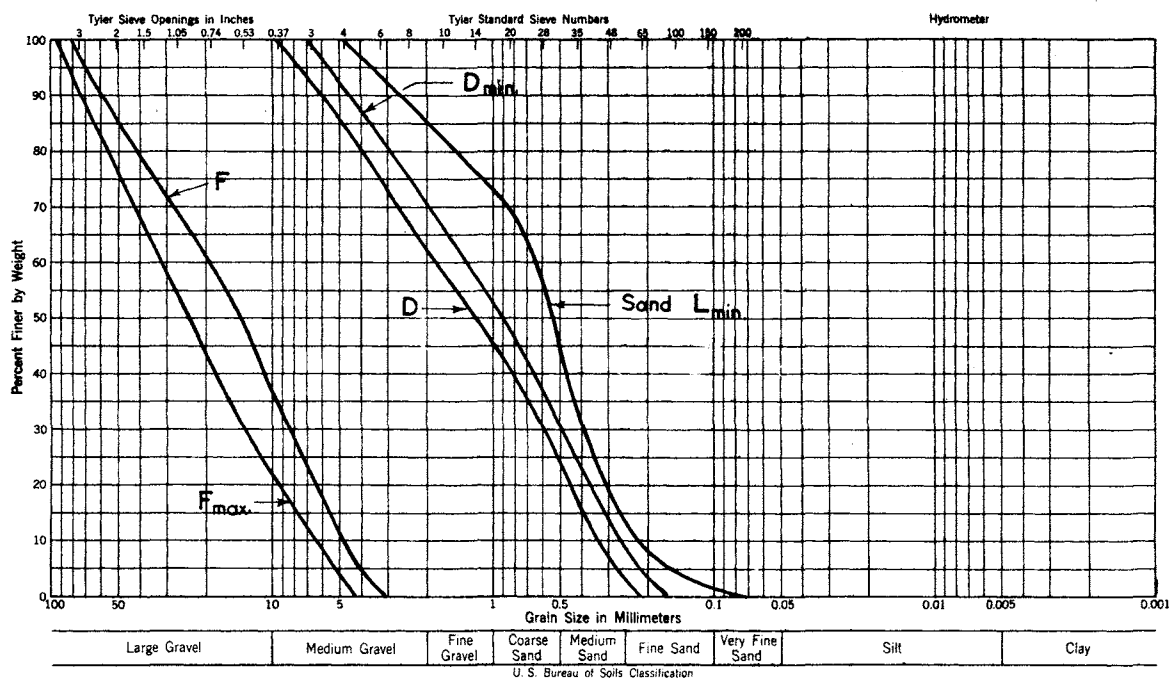gradation of F and the minimum permissible gradation of D; and one using

Figure 5. Tests 13, 14, and 15 -- gravels F and D, and sand L .

F_{max} with a sand L (a local Grenada material suggested by the Mississippi River Commission for consideration as a substitute for gravel D beneath the riprap) as a base material. Results of the tests of filter F are described below.

41. Test 13 (filter F vs base D).

$$\frac{D_{15} (F)}{D_{85} (D)} = 1.2 \qquad \frac{D_{15} (F)}{D_{15} (D)} = 14 \qquad \frac{D_{50} (F)}{D_{50} (D)} = 12$$

This combination was stable with steady downward flow and with vibration.

42. Test 14 (filter F_{max} vs base D_{min}).

$$\frac{D_{15} (F)_{max}}{D_{85} (D)_{min}} = 2.1 \qquad \frac{D_{15} (F)_{max}}{D_{15} (D)_{min}} = 25 \qquad \frac{D_{50} (F)_{max}}{D_{50} (D)_{min}} = 27$$

This combination was stable under steady downward flow but failed when

subjected to vibration. Again, as in the case when filter A_{max} failed to

hold L_{min} (test 5), the combination should have been stable according to

the stability ratio $(\dfrac{D_{15}\ Filter}{D_{85}\ Base})$ but failed when vibrated. It should

be noted though that the ratio of the 15 and 50 per cent sizes exceeded

20 and 25, respectively.

    43. <u>Test 15 (filter ^{F}max vs base ^{L}min)</u>.

$$\frac{D_{15}\ (F)_{max}}{D_{85}\ (L)_{min}} = 3.9 \qquad \frac{D_{15}\ (F)_{max}}{D_{15}\ (L)_{min}} = 29 \qquad \frac{D_{50}\ (F)_{max}}{D_{50}\ (L)_{min}} = 45$$

This combination was stable for steady flow, but failed when vibrated.

The fines of L_{min} passed through the filter readily and piping occurred

in the base material. It is believed the poor gradation of L_{min} (ex-

cessive amount of fines) contributed to the instability of the combination.

It should also be noted that the filter was 29 to 45 times coarser than

the base material at the 15 and 50 per cent sizes. Filter F is not con-

sidered suitable for draining sand L.

<u>Filter W</u>

    44. Gravel W (tests 16-18, figure 6) was tentatively designed as

the filter for the drainage wells at Enid and Grenada Dams. These filter

tests were run in conjunction with the drainage well tests reported in

Experiment Station Technical Memorandum 3-250, "Investigation of Wooden

Well Screens for Grenada, Enid, and Sardis Dams". This filter gravel

must meet some rather unusual and exacting requirements. First, it must

have a gradation and size which will prevent the inwash of foundation

sand, which may be quite fine in certain strata, into the well; second,

the filter must not wash through the well screen perforations into the

well; and third, the gravel should have a gradation such that segregation will be minimized as it is placed under water. The base material for tests 16 and 17 was a uniform, fine to medium sand Y. No foundation material was used in test 18, in which filter W was tested alone for stability in regard to 1/2-in. circular holes in a 1-in. thick wooden plate. A plate with 3/8-in. holes was used to retain filter W in test 16, and a plate with 1/4-in. by 2-in. slots was used to retain filter W in test 17. A discussion of the results of these tests follows.

45. <u>Test 16 (filter W vs sand Y)</u>. Wooden base plate with 3/8-in. holes.

$$\frac{D_{85} \ (W)}{3/8\text{-in. holes}} = 1.2 \qquad\qquad \frac{D_{15} \ (W)}{D_{15} \ (Y)} = 8.2$$

$$\frac{D_{15} \ (W)}{D_{85} \ (Y)} = 2.7 \qquad\qquad \frac{D_{50} \ (W)}{D_{50} \ (Y)} = 14.0$$
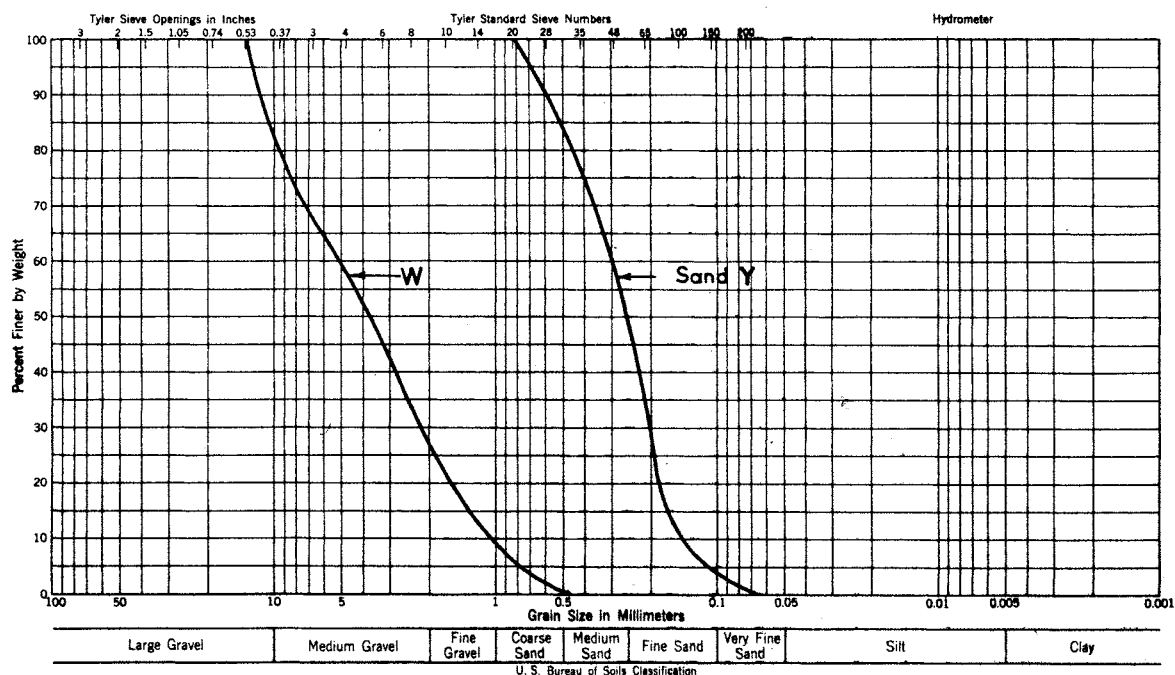

Figure 6. Tests 16, 17, and 18 -- gravel W and sand Y

This combination of filter W and sand Y was stable for both downward steady flow and downward flow with vibration. The 3/8-in. holes in the base plate also prevented any noticeable loss of gravel W.

46. <u>Test 17 (filter W vs sand Y)</u>. Wooden base plate with 1/4-in. by 2-in. slots. The filter and sand used in this test were the same as in test 16, the only difference in tests 16 and 17 was the base plate beneath the filter. As in test 16, the filter and sand were stable in this test and the 1/4-in. slots also prevented any noticeable loss of filter material. The ratio $\dfrac{D_{85} \text{ (W)}}{1/4\text{-in. slots}}$ was 1.7.

47. <u>Test 18 (filter W vs 1/2-in. holes)</u>. Wooden base plate with 1/2-in. holes. In this test an attempt was made to determine the limiting size of circular hole which could be used to drain gravel W. The ratio D_{85} of gravel W to the size of the holes was only 0.9, and by comparison with recommended criteria (max. = 1.0) was unsafe. However, there was no passage of filter material through the perforations with downward steady flow. The amount of material passing through the perforations after 40 minutes of severe vibration was about 0.3 per cent for a 6-in. layer of gravel W. This test demonstrated the ability of a plate with 1/2-in. holes to hold back a filter material, all of which would pass through a sieve with square openings equal in size to the diameter of the perforations. It was believed this was due principally to arching around the holes, which were about 2-1/2 in. apart, and to the fact that some particles which will pass square openings will not pass circular openings of the same diameter. Although the test indicated gravel W could be used adjacent to 1/2-in. perforations, 3/8-in. holes or 5/16-in. slots are recommended.

Group II -- Harrison Pit Filters

48. The filters and bases used in tests 19-30 (described below) were prepared by screening a composite sample, made by mixing samples taken from the north wall, center wall, and west wall of the Harrison Gravel Pit, located at Scobey, Miss. Because of its proximity to Grenada Dam, it was especially desired to utilize, if possible, material from this pit for the gravel blanket beneath the riprap. Samples of aggregate from the Harrison pit were furnished by the Vicksburg District, CE, and were assumed to be representative of the materials available in the pit. Grain-size curves for these samples are shown on figure 7. The average pit-run material, as sampled in the field, is shown on the figure as curve 4; this gradation is hereinafter designated as "H" gravel.
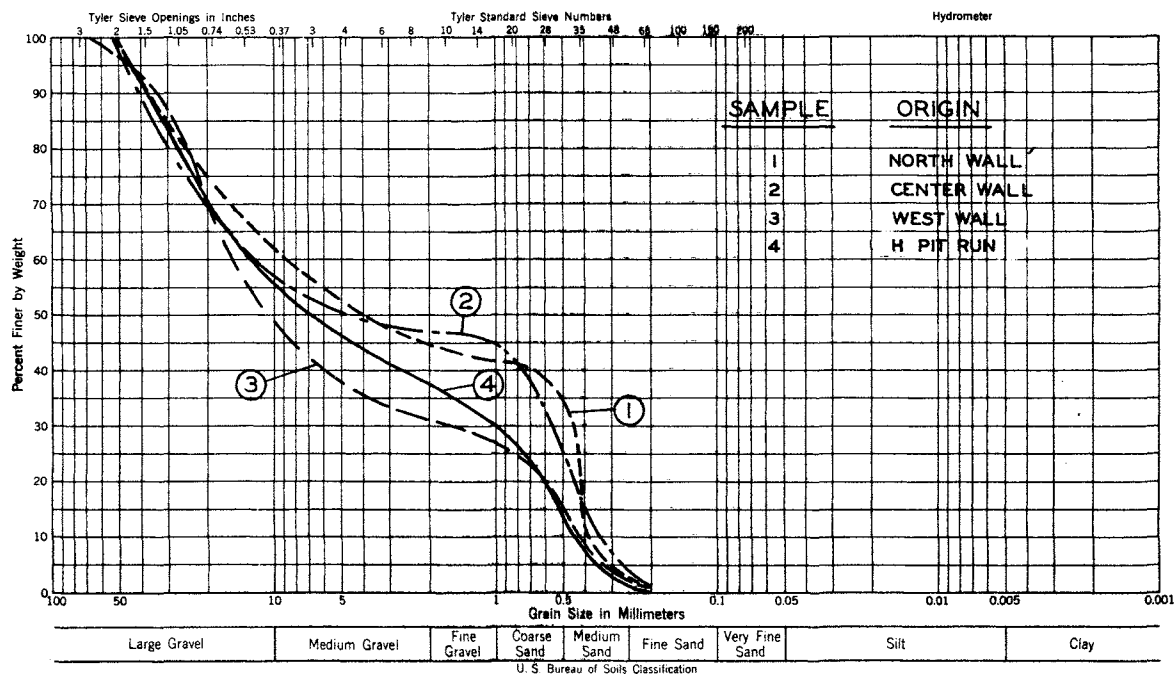
Figure 7. Harrison gravel pit samples

49. The objective of tests 19-30 was to design a filter material which could be used as the gravel blanket (either one or two layers, preferably one) under the dumped riprap on the upstream slope of Grenada Dam. If such a filter material could be made without excessive handling and wasting, it would be used in lieu of a layer of gravel F and a layer of gravel D, as originally proposed and as discussed in paragraph 40. If a one-layer gravel blanket could be devised from the Harrison pit materials which would be stable beneath the riprap and also protect the embankment, a considerable saving, both in initial and placement costs, would be effected.

50. The H material was washed to eliminate that portion finer than the No. 65 Tyler standard sieve, prior to any screening or separation, as the gravel would similarly be washed in the field. In the tests, the filters and base materials are designated by the screen size or number at which they were separated. Upward flow (as described in paragraph 18) through the test apparatus was used in all cases except tests 19, 22, and 27, in which the flow was downward. In tests 26, 28, 29, and 30, the filter material was harrowed with an iron rod after it was placed in the permeameter to segregate the material so that the finer particles would work to the bottom, leaving the coarser gravel on top. It is pointed out, in considering the results of the tests described in the following paragraphs, that the tapping and surging referred to were probably considerably more severe than any that a filter or base material would ever be subjected to in the field. However, where filters fail as a result of tapping or surging, there would be some doubt regarding their stability.

Filter H > #4

    51.   Test 19 (filter H > #4 vs base H < #4).

$$\frac{D_{15} \ (H > \#4)}{D_{85} \ (H < \#4)} = 4.7 \qquad \frac{D_{15} \ (H > \#4)}{D_{15} \ (H < \#4)} = 24 \qquad \frac{D_{50} \ (H > \#4)}{D_{50} \ (H < \#4)} = 42$$

In this test (figure 8) the pit-run material was separated on the No. 4

screen and that portion greater than the No. 4 screen was used as the

filter with that portion finer than the No. 4 screen as the base. The

combination was stable under downward steady flow at low gradients but

began to fail when the gradient was raised to 16. With no increase in

the gradient the combination stabilized. The gradient was then reduced

to approximately 1.0 and the permeameter vibrated. Immediate failure

of the base took place by subsidence and piping into the filter. The

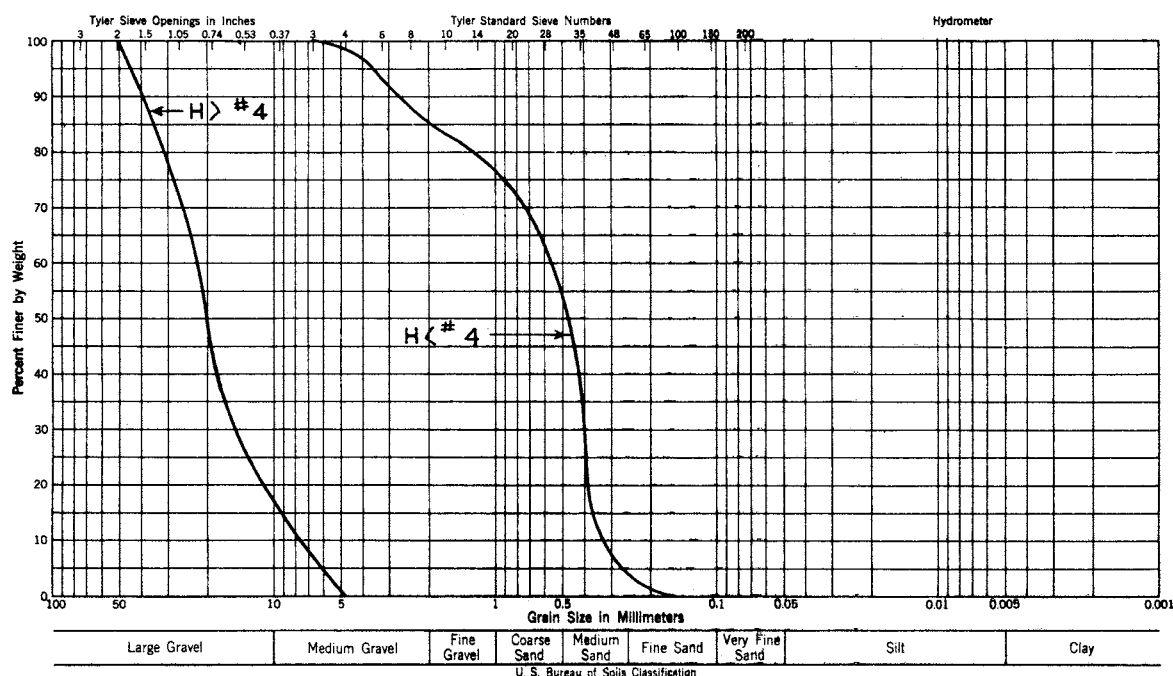combination is possibly safe for steady flow but very unstable when

Figure 8. Tests 19 and 20 -- H > #4 and H < #4

vibrated. The stability ratio of this combination (4.7) indicates that

it should be safe. However, a ratio of 4.7 is quite close to the maxi-

mum allowable (5.0). It should also be noted that filter H > #4 con-

sists almost entirely of large gravel, whereas the base consisted mostly

of sand, the finer portion of the gravel being about 25 to 40 times

coarser than the finer portion of the sand. It is generally believed,

as a tentative criteria, that the ratio D_{15} of filter to D_{15} of base

should be less than 20 and that the ratio D_{50} of filter to D_{50} of base

should be less than 25.

52. <u>Test 20 (filter H > #4 vs base H < #4)</u>. The same materials

were used in this test (figure 8) as in test 19, the only difference being

that the combination was subjected to upward flow rather than downward

flow. The combination failed quickly under steady flow (no vibration)

at a hydraulic gradient of 2 through the base material. All the fines of

the base material were washed either into or through the filter. The

combination was definitely unstable. The results of tests 19 and 20 in-

dicated the possibility that the pit-run material might not be stable

within itself. In order to check this indication, test 21 was run.

<u>H material, 12-in. layer, harrowed</u>

53. In order to check the stability of the Harrison pit-run ma-

terial, by itself, to the flow of water, a 12-in. layer of pit-run

material was placed in the permeameter and thoroughly harrowed by moving

a rod through the material after it was placed (test 21, figure 9). This

resulted in some segregation of the finer and coarser particles but not

as much as might have been expected. The lack of segregation is attributed

to the excess of sand. When the material was subjected to upward flow
at a hydraulic gradient of about 1.0, the fines began to migrate upward
through the coarser gravel until small sand boils could be noted on top
of the layer. With an increase of the gradient to 2.0, the fines con-
tinued moving to the surface until, with a gradient of 4.0, all the
fines smaller than the No. 28 screen had passed up through the overlying
gravel, leaving nothing but coarse sand and pea-size gravel in the bottom
of the layer. The poor grading of the pit-run material (see figure 9)
probably accounts for this failure. The pit-run material lacks fine
gravel and is essentially a mixture of coarse to medium sand and large
to medium gravel. It may be concluded that the Harrison pit-run ma-
terial is unstable within itself.
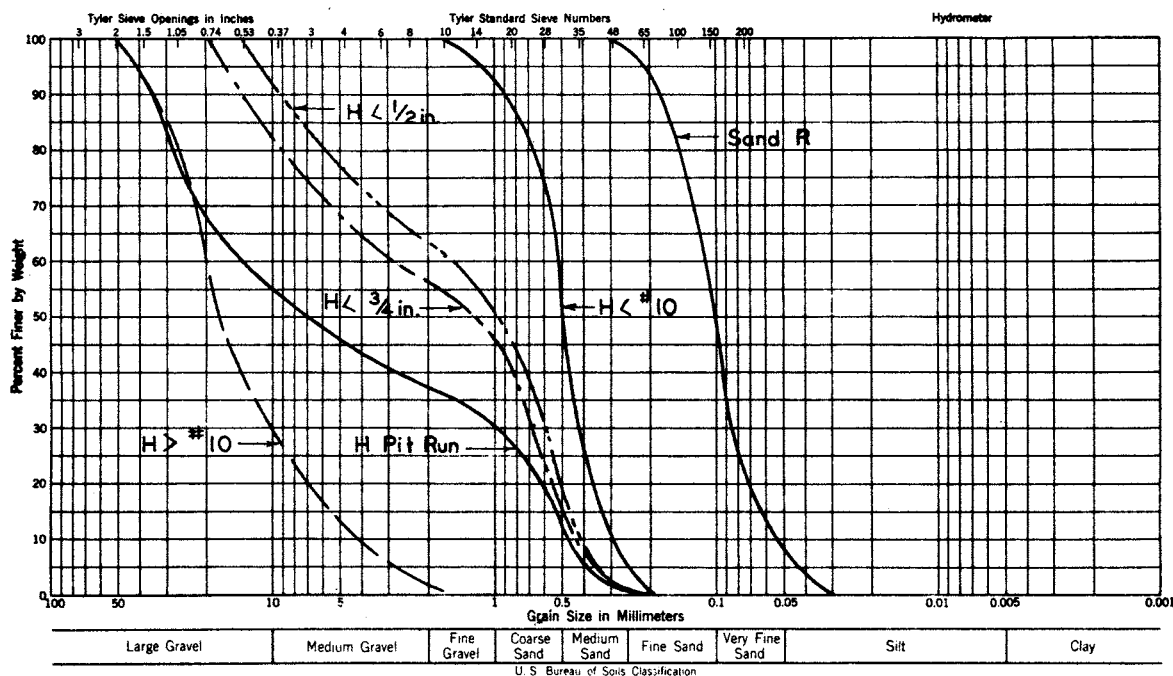

Figure 9. Tests 21 to 28
gravels H, H > #10, H < 3/4 in., H < 1/2 in., H < #10, and sand R

Filter H > #10

54. As test 20 indicated that H > #4 could not be depended upon
to drain that part finer than the No. 4 sieve, several tests (tests 22-
28, figure 9) were run with H > #10 as the filter with base materials of
H, H < 3/4 in., H < 1/2 in., H < #10, and sand R. (Sand R was a uniform,
fine sand used to test the effectiveness of filter H > #10 for draining
a material of this type.) The No. 10 screen was selected, since it is
not difficult to break a pit-run material at this point and because it
would comprise approximately 65 per cent of the pit-run material. Test
results are shown in the following paragraphs.

55. Test 22 (filter H > #10 vs base H).

$$\frac{D_{15} \ (H > \#10)}{D_{85} \ (H)} = 0.2 \qquad \frac{D_{15} \ (H > \#10)}{D_{15} \ (H)} = 10 \qquad \frac{D_{50} \ (H > \#10)}{D_{50} \ (H)} = 3$$

The stability ratio for this combination was 0.2, an unusual condition
and one which normally would indicate a very stable combination, yet the
filter failed when subjected to vibration with steady downward flow.
Reference to the grain-size distribution curves (figure 9) of these ma-
terials shows this ratio to be misleading. The curves are not parallel
and the base material is very poorly graded and extremely non-uniform.
The combination was safe with steady downward flow for gradients up to 8
but failed immediately and completely when vibrated. The failure con-
sisted of piping within the base material and the base material washed
through the filter. The failure, as in test 21, may be attributed to the
fact that the filter was not fine enough to hold back the fines of the
pit-run material and as the latter is not stable within itself, due to
its poor and extremely non-uniform gradation, the combination failed.

56. <u>Test 23 (filter H > #10 vs base H)</u>. This test was the same
as test 22, except that the flow was upward. The combination was stable
with steady flow but failed (with loss of fines) when surged. A compari-
son of the results of this test and test 22 indicates the combination to
be unstable either when vibrated with downward flow or surged with up-
ward flow.

57. <u>Test 24 (filter H > #10 vs base H < 3/4 in.)</u>.

$$\frac{D_{15} \ (H > \#10)}{D_{85} \ (H < 3/4 \ \text{in.})} = 0.5 \qquad \frac{D_{15} \ (H > \#10)}{D_{15} \ (H < 3/4 \ \text{in.})} = 11$$

$$\frac{D_{50} \ (H > \#10)}{D_{50} \ (H < 3/4 \ \text{in.})} = 15$$

This combination was stable with steady upward flow but failed with slight
vibration. The failure in this test was in the form of migration of the
base material up through the filter, the fines piling up on top of the
filter. The probable cause of failure was the lack of pea-gravel sizes
in the filter and the excess of sand in the base.

58. <u>Test 25 (filter H > #10 vs base H < 1/2 in.)</u>.

$$\frac{D_{15} \ (H > \#10)}{D_{85} \ (H < 1/2 \ \text{in.})} = 0.7 \qquad \frac{D_{15} \ (H > \#10)}{D_{15} \ (H < 1/2 \ \text{in.})} = 12$$

$$\frac{D_{50} \ (H > \#10)}{D_{50} \ (H < 1/2 \ \text{in.})} = 18$$

This combination was stable under steady upward flow, but surging caused
the fines in the base to migrate into and through the filter. This com-
bination was surged prior to being vibrated. When it was vibrated the
failure became more complete with further movement and piling up of

fines. This failure can probably be attributed to the lack of pea-gravel sizes in the filter and excess of sand in the base.

59. <u>Test 26 (filter H > #10 vs base H < 1/2 in.)</u>. This test was a repetition of test 25, with the exception that the filter was harrowed in placing. The combination was safe with steady upward flow but failed when surged. The failure was complete with loss of fines through the filter. Because of the harrowing, the filter ratios between the filter material and the base material were probably somewhat less than the values given for test 25.

60. <u>Test 27 (filter H > #10 vs base H < #10)</u>.

$$\frac{D_{15} \ (H > \#10)}{D_{85} \ (H < \#10)} = 7.3 \qquad \frac{D_{15} \ (H > \#10)}{D_{15} \ (H < \#10)} = 17$$

$$\frac{D_{50} \ (H > \#10)}{D_{50} \ (H < \#10)} = 36$$

This combination failed under steady downward flow at a hydraulic gradient of about 5. This failure was similar to that of tests 21 and 22, with piping and infiltration of the base into and through the filter, and again confirms the instability of the pit-run material within itself as proved in test 21. With a stability ratio of 7.3, this combination could be expected to fail without vibration or surging. The D_{50} of H > #10 was 36 times as great as the D_{50} of H < #10.

61. <u>Test 28 (filter H > #10 vs sand R)</u>.

$$\frac{D_{15} \ (H > \#10)}{D_{85} \ (R)} = 31 \qquad \frac{D_{15} \ (H > \#10)}{D_{15} \ (R)} = 84 \qquad \frac{D_{50} \ (H > \#10)}{D_{50} \ (R)} = 180$$

In this test a fine to very·fine sand R was used as a base material in

combination with H > #10 which had been harrowed when it was placed. The sand failed almost immediately by piping and migration when the hydraulic gradient was 2. No vibrating or surging was used because there was complete failure with upward steady flow. With a stability ratio of 31 this combination would not be expected to be stable; however, due to the harrowing, the ratio was probably less at the contact surface between the filter and base. Pit-run material coarser than No. 10 is too coarse to be used adjacent to a foundation material such as sand R.

Filter H > #28 harrowed

62. Consideration of all the tests utilizing Harrison pit-run material H, H > #4, or H > #10 indicated that none of these materials would be suitable as a filter material for draining either fine sand or finer soils. Material H was not even stable within itself. It was suggested during one of the informal conferences between representatives of the Mississippi River Commission, the Vicksburg District, and the Experiment Station, held in connection with the development of a suitable filter from the Harrison pit-run material, that the material be broken at the No. 28 sieve, placed in one 12-in. layer, and harrowed to segregate the various sizes within the filter. Test 29 was made to check the stability of H > #28 (harrowed) within itself; test 30 was made to determine whether H > #28 (harrowed) would safely drain a fine sand such as R. The results of these tests are discussed below.

63. Test 29 (filter H > #28, 12-in. layer). The purpose of this test was to check the stability of H > #28 within itself when subjected to upward flow, surging, and vibration. A 12-in. layer of pit-run

material coarser than No. 28 was placed in the permeameter and harrowed
so as to cause a certain amount of segregation. The material was then
subjected to steady upward flow, violent surging, and severe vibration.
The material was stable under all conditions; therefore it can be stated
that this material as harrowed is stable within itself. Grain-size
curves of the bottom 3 in., middle 3 in., and top 6 in. of the harrowed
H > #28 are shown on figure 10.

64. <u>Test 30 (filter H > #28, harrowed, vs sand R)</u>. Test 29, de-
scribed in the preceding paragraph, indicated that the portion of the
Harrison pit-run sand and gravel coarser than a No. 28 sieve would, when
harrowed, be stable within itself. The remaining question was whether
H > #28 (harrowed) would satisfactorily drain a very fine sand. Sand R,
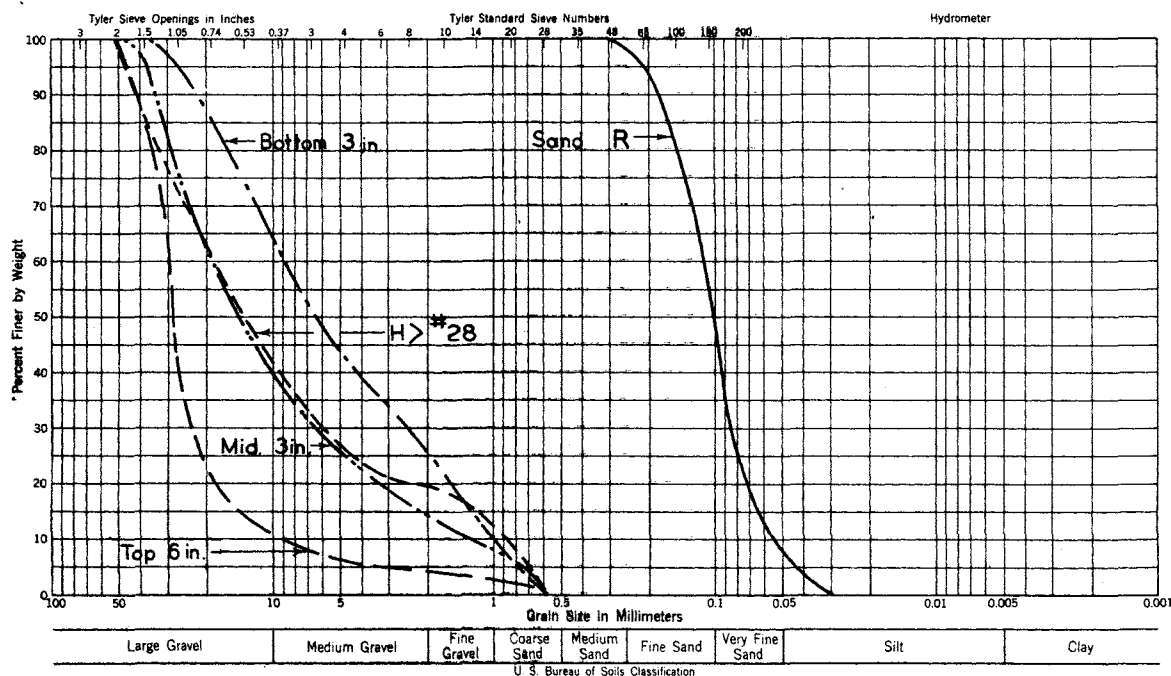a uniform, fine to very fine sand, was used as the base material in this

Figure 10. Tests 29 and 30
gravel H > #28 and sand R — gravel H > #28 harrowed

test. After placement of sand R, a 12-in. layer of H > #28 was placed

over R and harrowed. The gradation of the bottom 3 in. of the filter,

which was adjacent to the base material R, was assumed to be very similar

to the bottom 3 in. in test 29, shown on figure 10. It may be seen that

this lower portion was a well-graded material ranging from coarse sand

(10 per cent) to 1-in. gravel. The following filter ratios, based on the

gradation of the bottom 3 in. of filter, were obtained.

$$\frac{D_{15} \ (H > \#28)}{D_{85} \ (R)} = 7.6 \qquad \frac{D_{15} \ (H > \#28)}{D_{15} \ (R)} = 21 \qquad \frac{D_{50} \ (H > \#28)}{D_{50} \ (R)} = 140$$

No movement of base material R into the filter was observed with either

steady upward flow, surging, or vibration. Visual observations during the

test were necessarily limited to the periphery of the permeameter, and·

since it was considered possible that the movement of some grains might

have passed unnoticed, the filter and base were carefully examined at the

conclusion of the test. There was no evidence of infiltration of the

base into the filter. The stability of this combination is attributed to

the fact that the bottom 1/4 to 1/2 in. of the harrowed filter, which

was in actual contact with the base material, was observed to have a con-

siderably finer gradation than that of the bottom 3 in. of material in

test 29. Therefore, the filter ratios given above for the bottom 3 in.

of filter H > #28 may not be applicable. Unfortunately, no mechanical

analysis of the bottom 1/4 in. or 1/2 in. of the filter was made. From

this test it may be concluded that a 12-in. layer of H > #28, when har-

rowed so that the bottom 3 in. consists of particles 25 per cent of which

are finer than 2 mm, will satisfactorily drain a fine to very fine sand.

It is doubtful that such a material would drain a silty sand or sandy silt where there was an active flow of water from the silty sand into the filter. However, material H > #28, when properly harrowed, is believed satisfactory as a gravel blanket beneath riprap when placed next to the embankment material. Due to the segregation obtained by harrowing, the upper 6 in. of H > #28 consists almost entirely of coarse gravel, 60 per cent of which ranges between 1- and 2-in. stones. The stability of 1- to 2-in. stones beneath dumped riprap which has rather large voids is not definitely known, although the indications from Arkabutla and Sardis Dams are that, for exposure and other conditions similar to those occurring at these sites, 1-1/2-in. maximum size gravel is satisfactory.

Discussion of Test Results

65. All combinations of filters and base materials which had ratios of $\dfrac{D_{15} \text{ Filter}}{D_{85} \text{ Base}} < 4.5$ were stable for <u>steady flow</u> (either downward or upward) at gradients ranging from 1 to the maximum used (10 to 25), regardless of the gradation of either the filter or base. It is also pointed out that for <u>steady flow</u> all combinations except one (test 20) were stable when the above stability ratio was not greater than 5.0. Where the stability ratio exceeded 5.0, the filter usually failed under steady flow.

66. However, there were some combinations of filter and base materials (tests 5, 10, 14, 15, 19, 22-26) which met the above criterion, yet failed when subjected to <u>vibration</u> and/or <u>surging</u>. The criterion or stability ratio $\dfrac{D_{15} \text{ Filter}}{D_{85} \text{ Base}} < 5$ has frequently been used for designing filters, regardless of the gradation of either the filter or base material. Even though numerous filter-base combinations with non-uniform gradations

designed on the basis of this criterion have proved stable with steady
flow (and some with vibration), it should be remembered that this cri-
terion was developed primarily for filter and base materials which were
uniformly graded without a lack or excess of any particular size particles.
Where the filter or base materials are not uniformly graded, the design
should be checked by making a filter test in the laboratory before use in
the field. The shape of the grain-size curves of both the filter and
base material has considerable effect on the stability of the combination.

67. Where the filter and base material are more or less uniformly
graded without any particular excess or lack of certain particle sizes,
the filter criterion (stability ratio) $\dfrac{D_{15} \text{ Filter}}{D_{85} \text{ Base}} < 5$ is considered ap-
plicable and safe. However, it is also suggested that the combination
meet the following tentative filter-to-base ratios:

$$\frac{D_{15} \text{ Filter}}{D_{15} \text{ Base}} < 20 \quad \text{and} \quad \frac{D_{50} \text{ Filter}}{D_{50} \text{ Base}} < 25.$$

The ratio of the 15 per cent size of the filter to the 15 per cent size
of the base should also be greater than 4, so that the filter will have a
permeability sufficiently greater than that of the base. It may be noted
from table 1 that all filter-base combinations meeting the above criteria
were stable for both steady flow and with vibration, except the combina-
tions used in tests 22-26, which were very poorly graded. From a con-
sideration of the tests made in this investigation and previous filter
tests at the Experiment Station, it may be concluded that, for fairly
uniformly graded materials, filter combinations meeting the above filter
ratios will be stable for either upward or downward flow, surging, and a
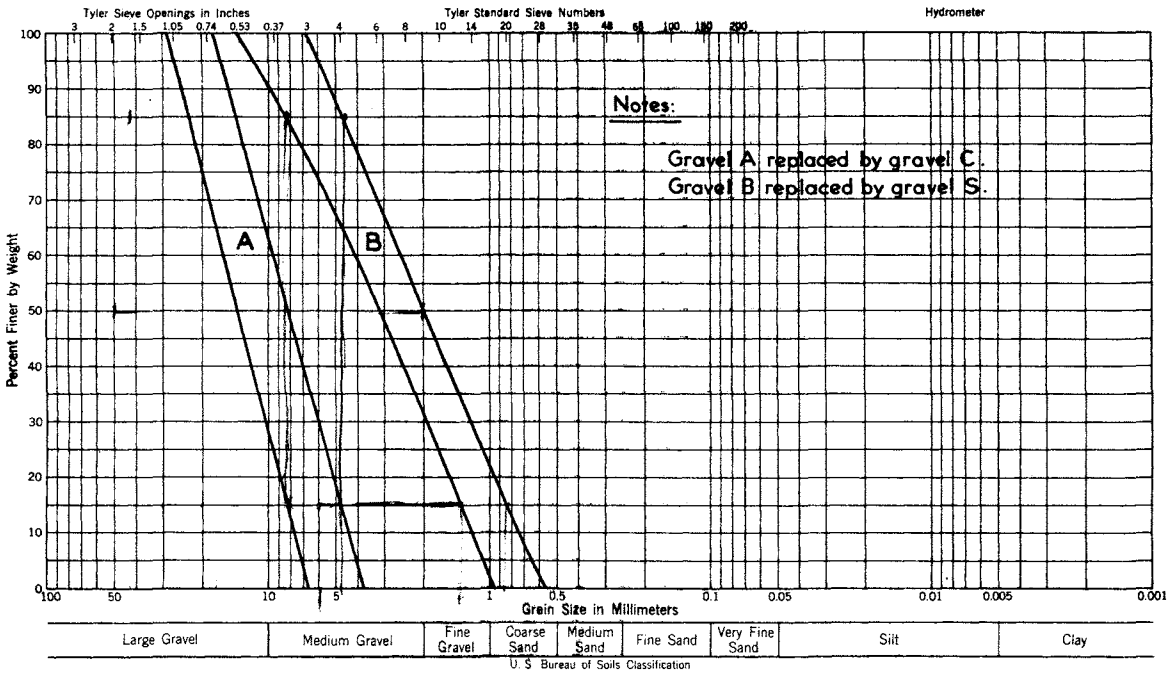normal amount of vibration.

68. In addition to meeting the criteria given in paragraph 67, the maximum and minimum limits of a filter should not deviate very much from the average design of the filter. Too broad a filter band, which might appear to be well graded, may permit a material theoretically acceptable to "wander" within the band so that it would not be suitable because of poor grading.

Filters -- Enid and Grenada Dams

69. Gravel A. Gravel A (figure 11) would be satisfactory as a filter for draining gravel B. However, in order to reduce the number of different types of filters, gravel A was replaced by gravel C in the final design.

70. Gravel B. Gravel B (figure 11) would be satisfactory as a filter for draining fine to medium sand. Where no vibration is expected, it probably would be satisfactory as a filter for fine sand. However, under no circumstances should gravel B be used as a filter for a very fine sand or finer soil. In the final design, gravel B and gravel W were replaced by gravel S (see paragraph 75).

71. Gravel C. Gravel C (figure 12) is considered satisfactory as a filter to drain gravel D (figure 12) or gravel S (figure 15), and is considered to have sufficient permeability to serve as a water-carrying layer of gravel. Collector pipes with 1/2-in. holes may be used in gravel C. A comparison of figures 9 and 12 will show that gravel C for Grenada Dam can probably be prepared by using that portion of the Harrison pit-run material coarser than a No. 10 Tyler sieve. Gravel C for Enid Dam can probably be similarly prepared by using that portion of the gravel

Figure 11.   Gravels A and B
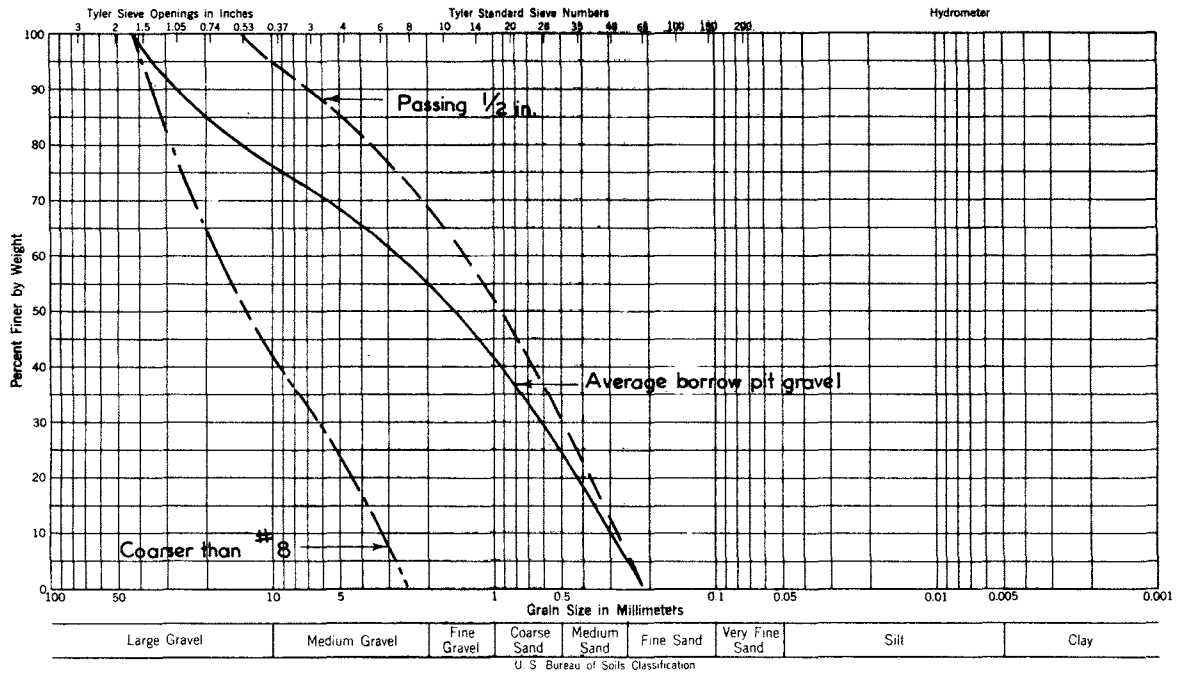

Figure 12.   Gravels C and D

pit material coarser than a No. 8 Tyler sieve (figure 13).

72. Gravel D. Gravel D (figure 12) is considered satisfactory for draining silty sands and all finer-grained soils. It would appear that gravel D for Grenada Dam could be prepared by screening out all material coarser than 1/2 in. from the Harrison pit-run material. However, due to the uneven gradation and the lack of "fine" gravel sizes in gravel H < 1/2 in. it is not considered as satisfactory as gravel D. The combination of gravel H > #10 vs H < 1/2 in. failed by surging in the laboratory tests. The Enid Dam gravel D can probably be prepared by screening out all gravel coarser than 1/2 in. (see figure 13).

73. Gravel F. Gravel F was originally designed to go directly below dumped riprap, but it was replaced by H > #28 (harrowed), subsequently called gravel R, as will be discussed later in paragraph 76. There was some doubt regarding the stability of gravel F as a filter for gravel D.

74. Gravel W. Gravel W (figure 14) was originally proposed as the filter for the relief wells at Enid and Grenada Dams, but at the request of the Mississippi River Commission gravels W and B were replaced by gravel S to reduce the number of filters (see paragraph 75). Gravel W was found to be a satisfactory filter for draining a fine to medium sand (see Waterways Experiment Station Technical Memorandum No. 3-250, "Investigation of Wooden Well Screens for Grenada, Enid, and Sardis Dams").

75. Gravel S. Gravel S (figure 15) was substituted for gravels B and W in order to reduce the number of filters at Enid and Grenada. This gravel was not tested in the laboratory but is considered satisfactory as a filter to drain sands or pervious fill and as a filter for the relief wells. The coarser limit of gravel S is considered to represent

Figure 13.   Enid Dam borrow pit gravels — average

Figure 14.   Gravel W

Tyler Sieve Openings in Inches   Tyler Standard Sieve Numbers   Hydrometer

Notes:

Gravel S substituted for gravels B and W.
Ref. 2nd wrapper ind. W.E.S., 8 Nov. 46.
Subject: Recommended changes and modifications
of specs. for Grenada Dam.

H

#28
1/2 in.

Gravel S

Percent Finer by Weight

Grain Size in Millimeters

| Large Gravel | Medium Gravel | Fine Gravel | Coarse Sand | Medium Sand | Fine Sand | Very Fine Sand | Silt | Clay |

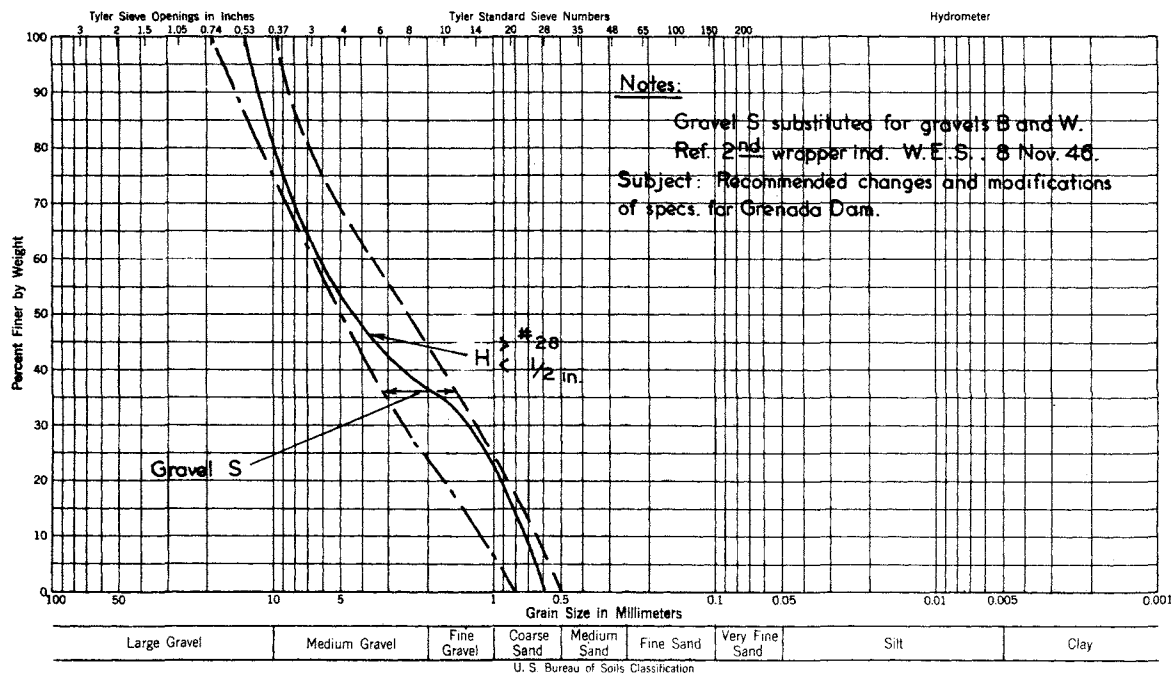U. S. Bureau of Soils Classification

Figure 15.   Gravel S

the absolute maximum for this filter. If there is any choice in the field

it would be preferable to make gravel S between the average and minimum

gradations.   For Grenada Dam it can probably be prepared by using that

portion of the Harrison pit material between the 1/2-in. and No. 28 Tyler

screens; for Enid Dam, by using the finer than 1/2-in. material from the

gravel borrow pits.   The foundation sands at Grenada and Enid Dams which

gravel S must drain are shown on figure 16.   The filter ratios for gravel

S_{max} and Enid $sand_{min}$ and Grenada $sand_{min}$ are given below.

	$\dfrac{D_{15}\ (S)_{max}}{D_{85}\ Sand_{min}}$	$\dfrac{D_{15}\ (S)_{max}}{D_{15}\ Sand_{min}}$	$\dfrac{D_{50}\ (S)_{max}}{D_{50}\ Sand_{min}}$
Enid........	3.8	10	17
Grenada.....	5.5	36	37

It is seen from the above tabulation that the finest of the Grenada sands

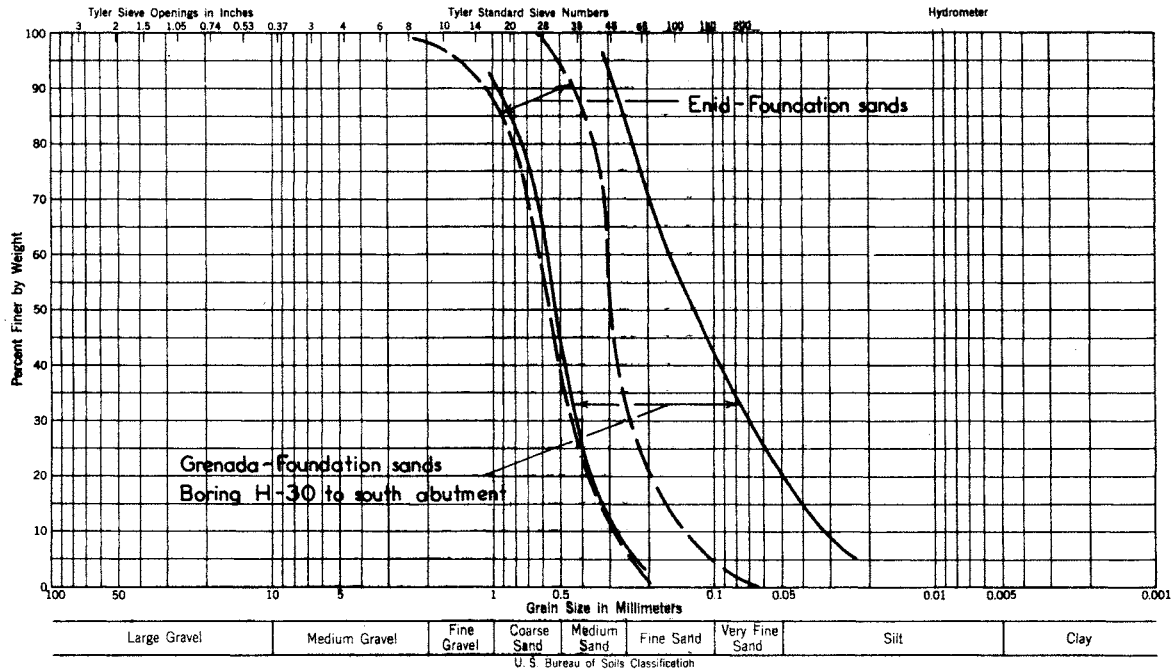is not protected satisfactorily according to the recommended criteria.
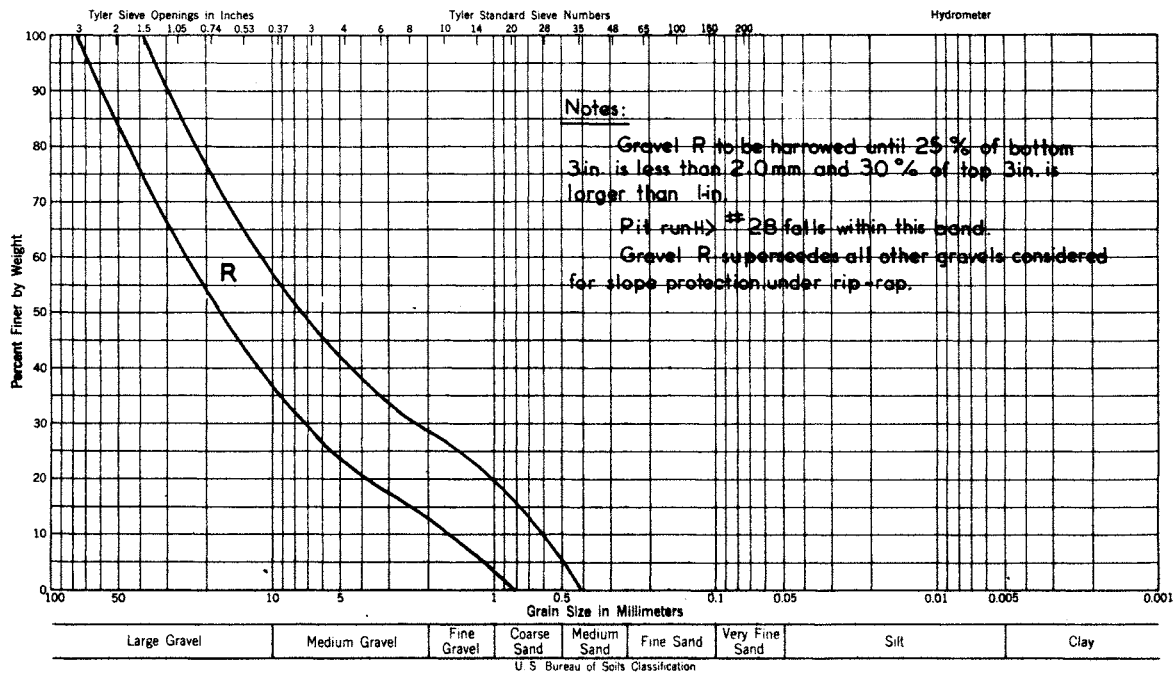
Figure 16.   Foundation sands

Figure 17.   Gravel R

However, this material occurs to only a limited extent and in thin strata, so that it was believed the stability ratios could be exceeded slightly for this limiting case.

76. Gravel R. A satisfactory gravel blanket beneath the riprap on the upstream slopes of Grenada Dam can be developed, utilizing the Harrison pit material by using all the material coarser than a No. 28 Tyler sieve, placing this as a 12- or 15-in. layer, and then harrowing until the bottom 3 in. consists of particles 25 per cent of which are finer than 2.0 mm, and the top 3 in. consists of gravel, 30 per cent of which is larger than 1 in. It is considered desirable to place a 2- to 3-in. layer of crusher spalls or large gravel (2- to 3-in. sizes) over this gravel blanket before placing the riprap. Gravel R (figure 17) is also considered satisfactory as the upstream slope protection at Enid Dam.

77. A consideration of the tests previously discussed emphasizes the sensitiveness of filter stability to the gradation of the gravel. Therefore, there should be careful field control and inspection to insure that the filters as placed have gradations more or less parallel with the limits of the filter band and are within the limits given in this report.

PART IV: CONCLUSIONS

General

78. For filter and base materials that are more or less uniformly graded, without any particular excess or lack of certain particle sizes, the filter criterion (stability ratio)

$$\frac{D_{15} \text{ Filter}}{D_{85} \text{ Base}} < 5$$

appears satisfactory for design purposes. However, the tests made in this and previous investigations indicate the desirability of the following additional criteria for filters and bases:

$$\frac{D_{15} \text{ Filter}}{D_{15} \text{ Base}} < 20 \quad \text{and} \quad \frac{D_{50} \text{ Filter}}{D_{50} \text{ Base}} < 25.$$

Where either the filter or base materials are poorly graded, the design should be checked by making filter tests in the laboratory before use in the field.

Enid and Grenada Dam Filters

79. Gravel D should be used where silty sands or finer-grained soils are to be drained.

80. Gravel S should be used where sands are to be drained.

81. Gravel C may be used as a filter to drain gravels D or S, and as a water carrier. Gravel C is also suitable as a filter around collector pipes with 1/2-in. holes.

82. A satisfactory gravel blanket beneath the riprap at these dams can be prepared from locally-available sandy gravels (Harrison pit at Grenada and gravel borrow areas at Enid) by using all the sand and gravel coarser than a No. 28 Tyler sieve, placing this as a 12- or 15-in. layer, and then harrowing until the bottom 3 in. consists of particles 25 per cent of which are finer than 2 mm, and the top 3 in. consists of gravel, 30 per cent of which is larger than 1 in. It would be desirable to place 2 or 3 in. of crusher spalls or large gravel (2- to 3-in. sizes) over this gravel blanket before placing the riprap.